

ELECTRONIC FUNDAMENTALS

EXPERIMENT LESSON 36

BANDWIDTH EXPERIMENTS



RCA INSTITUTES, INC.
A SERVICE OF RADIO CORPORATION OF AMERICA
HOME STUDY SCHOOL
350 West 4th Street, New York 14, N. Y.

Experiment Lesson 36

INTRODUCTION

Tuned circuits form an important part of almost all electronic equipment. In many applications, the tuned circuits are also *coupled* circuits; that is, the signal is transferred from one circuit to the next by inductive coupling between the coils of the tuned circuits. Proper operation of the equipment depends upon the tuned circuits having the correct band-width and selectivity. In this experiment lesson you will find out about some of the factors that control the bandwidth and selectivity of tuned circuits.

The ideal response curve of a tuned circuit is shown in Fig. 36-1. The features of the response curve that make it ideal are the flat top and the steep vertical sides. The flat top of the curve shows that the circuit has equal response for a certain band of frequencies on each side of the center frequency. The steep vertical sides indicate very good selectivity due to the high rejection for frequencies outside of the bandpass. The width of the flat top is determined by the needs of the equipment. Both amplitude and frequency modulation produce sidebands on each side of the carrier frequency. The higher the modulating frequency, the further the sidebands are separated in frequency from the carrier. For a high-fidelity receiver, all the sidebands should receive equal amplification, and this requires a flat-topped

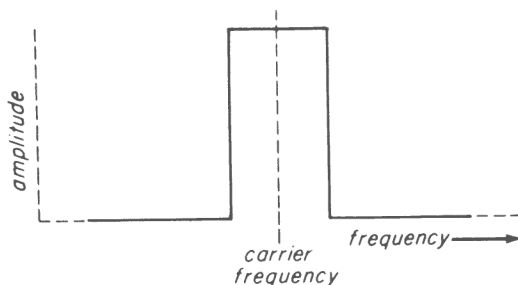


Fig. 36-1

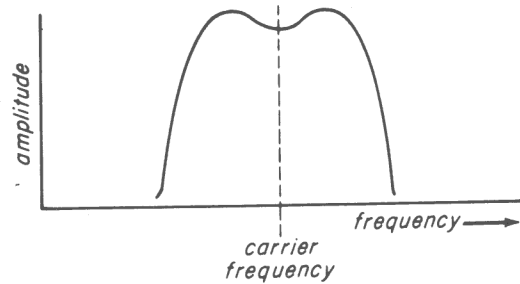


Fig. 36-2

curve. For extremely selective circuits, such as those used in communications receivers for code reception, the response curve of tuned circuits should be very narrow with very steep sides, or *skirts*, as the sides of the response curve are called.

The ideal response curve of Fig. 36-1 is not realizable in practice. A reasonably flat-topped curve, such as may be found in a high-fidelity receiver, is shown in Fig. 36-2. The bandwidth depends on the type of receiver; about 10 kc to 20 kc is the approximate bandwidth figure for a high-fidelity AM receiver, and about 200 kc for an FM receiver. For television receivers, the bandwidth may be as high as 6 *megacycles*. Wide response curves like those shown in Fig. 36-2 can be obtained in a number of ways, which will be shown in the experiments. Bandwidth is always obtained at the expense of gain, as these experiments will show.

The response curve of a very selective circuit, such as might be found in a communications receiver is shown in Fig. 36-3. The bandwidth of such a circuit may be only a few hundred *cycles*. In order to obtain such high selectivity, the circuit *Q* must be very high. The losses in the circuit must be very low. This means that the coils must be wound so as to keep their a-c resistance low, and there must be minimum loading of the tuned circuit by other circuits, etc.

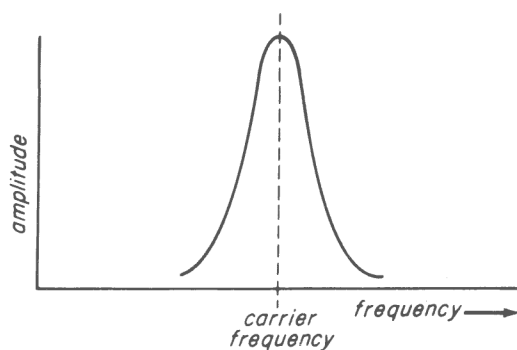


Fig. 36-3

EXPERIMENT 36-1

To study the effects of varying the closeness of coupling on the bandwidth and selectivity of a tuned circuit.

Information. Coupled circuits are circuits in which the coils are arranged so that the magnetic flux of one coil links the turns of the second coil, as in Fig. 36-4. The signal or energy in one circuit is transferred to the other circuit by magnetic coupling. The extent to which the lines of force of the one coil links to the other coil is described as the closeness of coupling. A numerical constant k , called the *coefficient of coupling*, is used to measure the amount of coupling. However, for the purposes of this experiment it will be sufficient to refer to the amount of coupling as loose coupling or tight coupling. The effect of varying the amount of coupling is not the same for all circuits. It depends on whether only the primary or secondary is tuned, or on whether they are both tuned. In this experiment you will examine the effect of varying the coupling in the circuit of Fig. 36-5, where only one of the coupled circuits is tuned. This circuit is called a *single-tuned circuit*; when

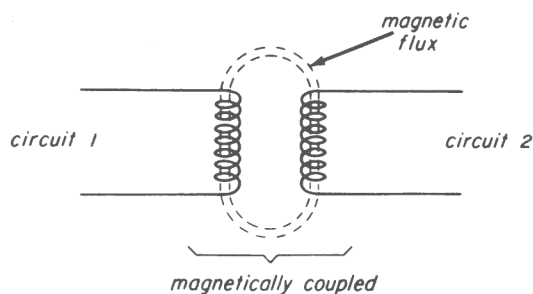


Fig. 36-4

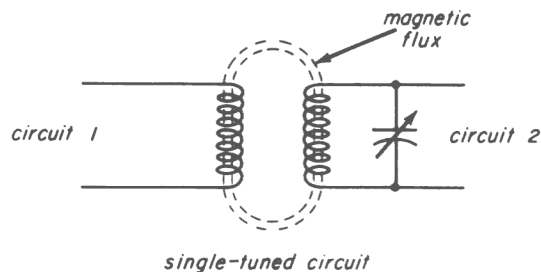


Fig. 36-5

both primary and secondary are tuned as in Fig. 36-6, it is called a *double-tuned circuit*. You will find that the effect of increasing the coupling in a single-tuned circuit is to lower the Q of the circuit, broaden the response, and decrease the selectivity.

Procedure.

Step 1. To make it easier to read frequencies in the vicinity of 600 kc, mark off the interval on each side of the 600-kc mark on the signal generator into five equal parts. Figure 36-7 may be used as a guide for the spacing. Each resulting small space is equal to 5 kc.

Step 2. Connect the signal generator cable across the 3-turn antenna-coupling coil.

Step 3. Turn the signal generator on and allow it to warm up. Set the signal generator to Band B, 600 kc, maximum r-f output, and turn the modulation switch off.

Step 4. Remove the converter tube from the radio receiver.

Step 5. Set up the meter to the 15 VAC range, and insert the positive test prod into pin 8 of the converter socket on the top of the chassis. Connect the other meter lead to the chassis.

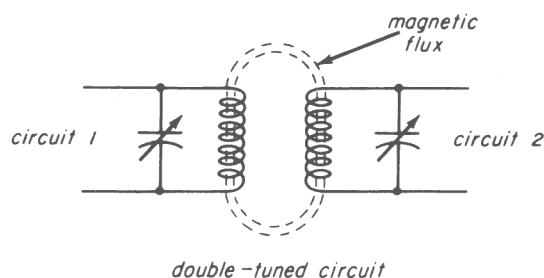


Fig. 36-6



Fig. 36-7

Step 6. Turn on the receiver and allow the tubes to warm up.

Step 7. Adjust the receiver tuning dial to the 600-kc point on the dial, and tune the slug of the antenna coil for maximum deflection.

Step 8. Adjust the RF ATTEN control on the signal generator for exactly 10 volts output. If necessary to obtain sufficient output, move the turns of the coupling coil closer to the antenna coil winding, and then retune.

Step 9. Take data for plotting a response curve of the circuit by filling out Table A.

TABLE A - LOOSE COUPLING	
Frequency (kc)	Relative Output
575	
580	
585	
590	
595	
600	
605	
610	
615	
620	
625	

Step 10. Disconnect the signal generator from the antenna-coupling coil. Slip the 20-turn pickup coil (made in a previous experiment) over the antenna coil, and connect the signal generator cable across the leads of this pickup coil.

Step 11. Reset the signal generator to exactly 600 kc and retune the slug for maximum deflection. Adjust the RF ATTEN control of the signal generator for exactly 10 volts output.

Step 12. Take data for plotting a response curve of this circuit by filling out Table B.

TABLE B - TIGHT COUPLING	
Frequency (kc)	Relative Output
575	
580	
585	
590	
595	
600	
605	
610	
615	
620	
625	

Step 13. Turn off the receiver. Remove and put aside the 20-turn pickup coil.

Step 14. Plot curves from the data in Tables A and B on the graph paper provided at the end of this booklet.

How does the closeness of coupling affect the response curve?

Discussion. Typical results obtained in this experiment are given in Table C.

Curves plotted from this data are shown in Fig. 36-8. As can be seen from the curves, increasing the coupling lowers the Q of the tuned circuit and decreases its selectivity.

TABLE C - RELATIVE OUTPUT

Frequency (kc)	Loose Coupling	Tight Coupling
575	0.5	5.5
580	1.0	6.5
585	1.5	8.0
590	2.5	9.0
595	4	9.5
600	10	10
605	4	9.5
610	2.5	9
615	1.5	8
620	1.0	7.0
625	0.5	5.5

When you are coupling an antenna to a tuned circuit like the one in this experiment, couple the antenna as loosely as possible; otherwise, the selectivity of the tuned circuit will be destroyed.

EXPERIMENT 36-2.

To study a method of determining the Q and the effective a-c resistance of a radio frequency coil.

Information. The bandpass and selectivity of a tuned circuit are related by the formula

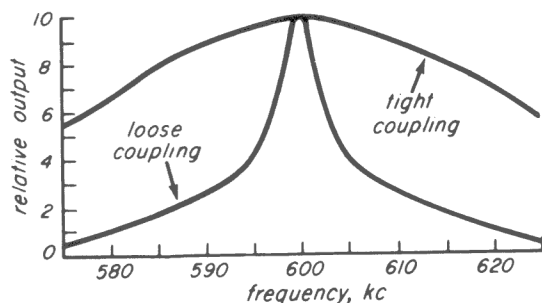


Fig. 36-8

$$Q = \frac{f_r}{f_1 - f_2}$$

where

Q = the circuit Q ,

f_r = the resonant frequency of the circuit,

f_1, f_2 = the frequencies on each side of the resonant frequency at which the voltage response falls off to 0.707 of its maximum value as shown in Fig. 36-9. These points are the *half power* points, because reducing the voltage by 0.707 cuts the power in half.

If the half-power frequencies are known, the Q of the circuit can be easily calculated. Since the capacitors used in r-f circuits are practically lossless at broadcast frequencies, the Q of the circuit is the Q of the coil. For example, a circuit has the response shown in Fig. 36-10. Here, f_r is 1,000 kc, and $f_2 - f_1$ is 20 kc. Then,

$$Q = \frac{f_r}{f_2 - f_1} = \frac{1,000 \text{ kc}}{20 \text{ kc}} = 50$$

The effective a-c resistance of a coil is related to its Q by the formula.

$$Q = \frac{2\pi f_r L}{R}$$

or

$$R = \frac{2\pi f_r L}{Q}$$

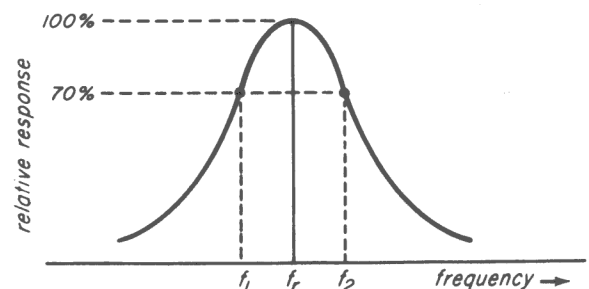


Fig. 36-9

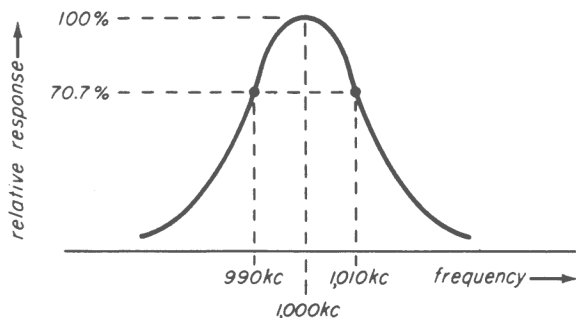


Fig. 36-10

If, in the example of Fig. 36-10, the coil has an inductance of 100 microhenries, its *a-c* resistance is found as follows:

$$\begin{aligned}
 R &= \frac{2\pi f_r L}{Q} \\
 &= \frac{6.28 \times 1,000 \times 10^3 \times 100 \times 10^{-6}}{50} \\
 &= \frac{628}{50} = 12.5 \text{ ohms}
 \end{aligned}$$

Procedure.

Step 1. Solder a 10 k-ohm $\frac{1}{2}$ -watt resistor in series with the free lead of the 3-turn antenna coupling coil.

Step 2. Connect the signal generator across the 3-turn coupling coil, through the series 10 k-ohm resistor. The resistor serves to isolate the signal generator from the tuned circuit.

Step 3. The 10 k-ohm resistor reduces the r-f voltage so that it is too low to be read by the meter. Therefore the 6SA7 will also be used to amplify the r-f voltage before it is applied to the meter. To do this, disable the receiver local oscillator by unsoldering the 50- μ mf capacitor from pin 5 of the 6SA7 converter tube.

Step 4. Replace the 6SA7 tube in the socket.

Step 5. Check to see that the positive meter lead is in the OUTPUT jack. Connect the meter to the plate (pin 3) of the 6SA7 tube, and chassis. Arrange your meter connections so that the chassis can be right side up (If necessary, solder a small piece

of hookup wire to pin 3 of the 6SA7 tube for the meter connection.)

Step 6. Turn on the receiver and allow the tubes to warm up.

Step 7. Set the signal generator to exactly 600 kc.

Step 8. Tune the slug of the antenna coil until it is just coming out of the coil form. Then tune the capacitor for maximum response. Then you can make a fine adjustment for resonance by using the slug.

Step 9. Using the RF ATTEN control, adjust the output to give some convenient value on the meter, say 10 volts.

Step 10. Tune the signal generator above 600 kc carefully until the output falls to 0.7 of the maximum value, or, in this case, 7 volts.

Step 11. Estimate the frequency from the dial scale *as carefully as possible*, and record it here:

 $f_1 =$

kc

Step 12. Tune the signal generator below 600 kc carefully until the output again falls to 0.7 of the maximum value.

Step 13. Estimate the frequency from the signal generator scale *as carefully as possible*, and record it here:

 $f_2 =$

kc

Step 14. Turn off the receiver.

Step 15. Compute the bandpass:

 $f_1 - f_2 =$

kc

Step 16. Compute the Q of the circuit and record it here:

$$Q = \frac{f_r}{f_1 - f_2} = \frac{600 \text{ kc}}{f_1 - f_2} = \boxed{}$$

Step 17. Compute the a-c resistance of the antenna coil. (The inductance of the coil with the slug positioned as in Step 8 is about 250 microhenries.)

$$R = \frac{2\pi f_r L}{Q} = \boxed{}$$

How does this compare with the d-c resistance of the antenna coil? Why?

Discussion. Typical results for this experiment are an f_1 of about 598.5 kc, and an f_2 of about 601.5, so that $f_2 - f_1 = 3$ kc. This gives:

$$Q = \frac{f_r}{f_2 - f_1} = \frac{600 \text{ kc}}{3 \text{ kc}} = 200$$

and

$$\begin{aligned} R &= \frac{2\pi f_r L}{Q} \\ &= \frac{6.28 \times 600 \times 10^3 \times 250 \times 10^{-6}}{200} \\ &= \frac{6.28 \times 6 \times 0.25}{2} = 5 \text{ ohms (approx)} \end{aligned}$$

The d-c resistance of the antenna coil is about 1 ohm. The increase is due to the higher losses at r.f., due to eddy currents, skin effect, core losses, etc.

Similar results for Q and a-c resistance can be obtained by getting the half-power frequencies from the response curve of Fig. 36-8.

EXPERIMENT 36-3

To study a method of coupling circuits together by means of a low-impedance link.

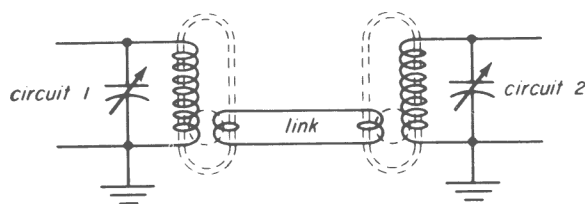


Fig. 36-11

Information. Energy can be transferred between two circuits that are not magnetically coupled together by means of *link coupling*. This type of coupling is shown schematically in Fig. 36-11. The *link* consists of two coils, each made up of a few turns of wire, connected together to form a closed circuit. One of the coils of the link is placed near each of the two tuned circuits. Note that the link coils are placed near the r-f ground end of each of the tuned circuits to minimize the disturbing effect of the link. Because they are made up of a relatively small number of turns, the link coils have very low impedance, and this type of coupling is termed low-impedance coupling. Because of the low impedance, any capacity shunted across the link will have little effect. Thus, shielded cable can be used for the link without the high capacity of this cable causing detuning. As long as the length of the link is small compared to a wavelength at the operating frequency, its length is not critical.

Procedure.

Step 1. Disconnect the signal generator from the pickup coil and unsolder the 10 k-ohm resistor from it. Connect the resistor in series with one of the leads of the loop antenna. Connect the signal generator across the leads of the loop antenna, through the series resistor. The high side of the cable should be connected to the resistor, and the ground side of the cable should be connected directly to the loop antenna.

Step 2. Connect your clip lead between the chassis and the ground cable of the signal generator.

Step 3. Check to see that the meter is set up to the 15 VAC range, and is connected to pin 3 of the 6SA7 tube. Arrange the meter

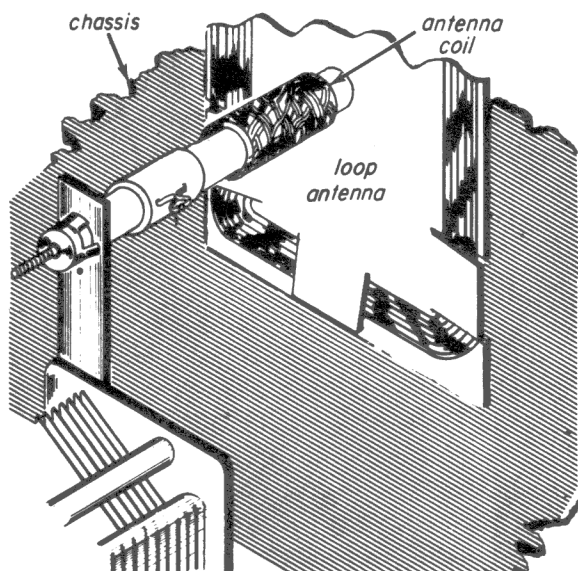


Fig. 36-12

connections, as previously described, so that the chassis is right side up.

Step 4. Turn on the receiver and allow the tubes to warm up.

Step 5. Hold the loop antenna near the antenna coil on the chassis, with the loop perpendicular to the antenna coil as shown in Fig. 36-12, and vary the position of the loop for maximum deflection on the meter. (Be careful not to knock off the signal-generator cables while doing this.) The receiver r-f circuit should be tuned to 600 kc from the last experiment.

Record the maximum reading obtained here:



Step 6. Separate the loop antenna from the chassis by about one foot and turn the loop

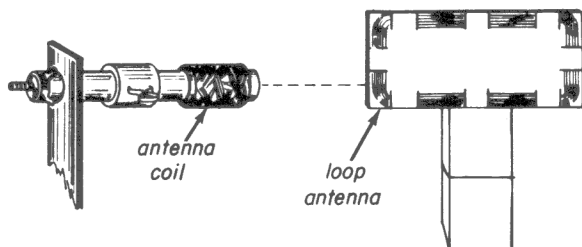


Fig. 36-13

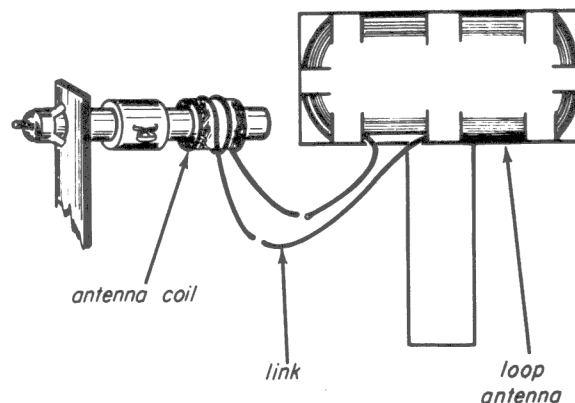


Fig. 36-14

so that it is in the same plane as the antenna coil, as shown in Fig. 36-13. Check to see that the signal generator is still connected to the loop. There should be no pick-up of signal from the loop, and the meter deflection should be zero.

Step 7. Cut off about 4 feet of hookup wire or magnet wire, strip the ends, and solder the ends together to form a closed loop.

Step 8. Wind one turn of the loop you just made around the antenna coil, and wrap one turn around the loop as shown in the Figure 36-14.

Step 9. Retune the tuning capacitor for maximum response.

Step 10. What is the meter deflection? How does it compare with the maximum voltage obtained in Step 5?

It should be possible to obtain as much voltage through link coupling as the maximum obtainable by direct coupling in Step 5.

EXPERIMENT 36-4.

To study the effect of varying the closeness of coupling in a double-tuned circuit.

Procedure.

Step 1. Couple the loop antenna to the antenna coil as in the previous experiment.

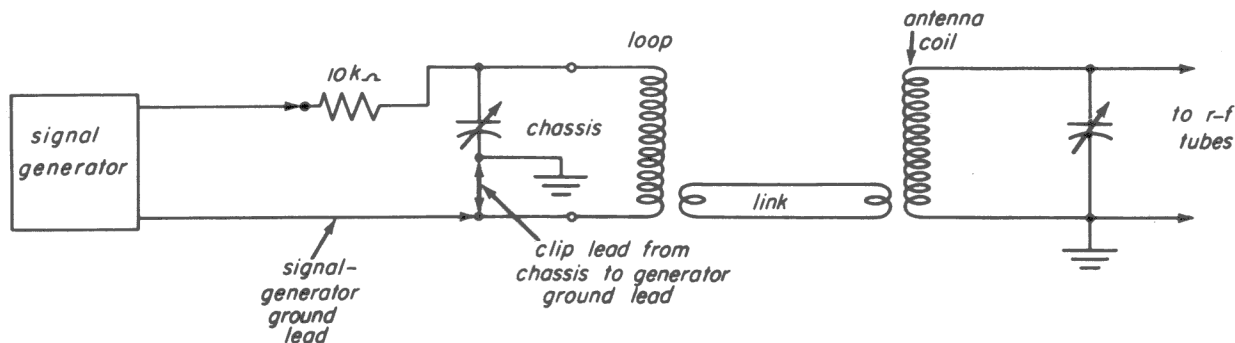


Fig. 36-15

Step 2. Since a double-tuned circuit is required, the oscillator section of the tuning capacitor will be temporarily used to tune the loop antenna.

Disconnect the lead from the stator terminal of the oscillator section of the tuning capacitor and tape this lead up. Connect a piece of hookup wire between this stator terminal and the undergrounded lead of the loop antenna. The circuit that you should now have is shown in the schematic diagram of Fig. 36-15.

Step 3. Move the one turn link to the very edge of the antenna coil, as shown in Fig. 36-16, to obtain loose coupling.

Step 4. Both tuned circuits must be tuned to resonance at the same frequency. Because the loop antenna that you made in a previous experiment has less inductance than the antenna coil, use the following procedure:

- a. Tune the signal generator to 750 kc.
- b. Set the receiver tuning dial to the 600 mark.
- c. Tune the slug of the antenna coil for maximum response.

Step 5. Rotate the signal generator tuning dial to the low end of the band; then slowly rotate it up to and past 750 kc while you observe the meter.

Notice that there is only one peak and that the output falls off gradually on either side of this peak.

Step 6. If you wish, you can take data for plotting a response curve. In order to do so, adjust the RF ATTEN control for some convenient output value — for example, 10 volts at 600 kc — and take readings at convenient intervals on each side of 750 kc.

Step 7. Increase the coupling between the link and the antenna coil by moving the link over to the center of the antenna coil.

Step 8. Reset the signal generator to 750 kc and readjust the tuning capacitor for minimum response.

Step 9. Rotate the signal generator tuning dial to the low end of the band. Then slowly rotate it up to and past 750 kc while you observe the meter. How many peaks are there now? What is the effect of overcoupling the double tuned circuit? How does it differ from the result obtained by overcoupling a single tuned circuit? If you wish, you can take data for plotting the response curve.

Step 10. Turn off the receiver. Disconnect the signal generator, the link, and the 10 k-ohm resistor. Remove any short pieces of wire attached to the 6SA7 tube for testing purposes.

Step 11. Resolder the lead to the oscillator section of the tuning capacitor.

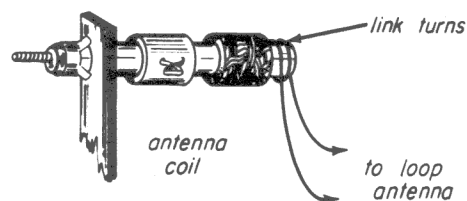


Fig. 36-16

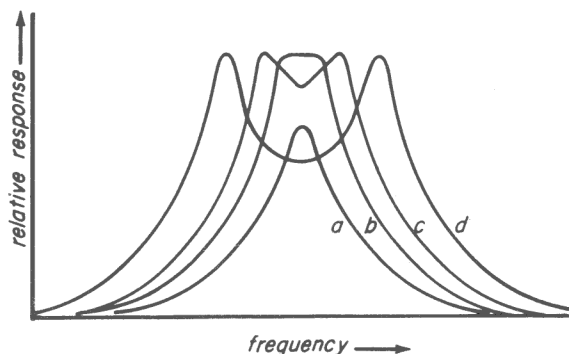


Fig. 36-17

Step 12. Resolder the 50- $\mu\mu\text{f}$ capacitor to pin 5 of the 6SA7 converter tube.

Step 13. Realign the r-f section of the receiver according to procedures given in the alignment experiment lesson.

Discussion. The various response curves obtained for different degrees of coupling between two resonant circuits are shown in Fig. 36-17. Very loose coupling gives the high Q curve shown at *a*. As the coupling is increased, the response increases, but selectivity is decreased, as shown at *b*. As coupling is increased further, the curve begins to flatten out slightly on top, as shown at *c*. A further increase in coupling causes two peaks or humps to appear in the response curve, as at *d*. The greatest amount of coupling that does not produce double peaks in the response curve, represented by curve *c*, is called *critical coupling*.

Note that the double peaks of Fig. 36-17 are equally spaced on each side of the center frequency, and have the same amplitude as the critical coupling peak. These curves apply only to double tuned circuits like that shown in Fig. 36-6, where both circuits are tuned exactly to the same frequency and have the same Q . In the experimental setup, link coupling must be used between the two circuits, and the circuits do not have the same Q . For these reasons, the experimental results will not be exactly the same as the results given by the theoretical curves of Fig. 31-17. However, the double peaks that are produced illustrate the general principle of overcoupling double-tuned

circuits. This method may be used, either by itself or in combination with other methods, to obtain the wide bandpass required for high-fidelity sound receivers or for television receivers.

EXPERIMENT 36-5.

To observe how a wideband response can be obtained by *stagger tuning* of the i-f amplifiers.

Information. If all the tuned circuits of the intermediate frequency amplifier are tuned to the same frequency, the selectivity of each circuit contributes to the total selectivity. The result is a highly selective curve. This has already been demonstrated in a previous experiment. However, if the circuits are *stagger tuned*, that is, if each of the tuned circuits of the i-f amplifier is tuned to a slightly different frequency, the bandpass of the circuit can be broadened. Gain is lost in the process, since bandwidth is obtained at the expense of gain.

The principles of stagger tuning are shown in Fig. 36-18. The four stages of Fig. 36-18*a* are tuned to four different frequencies, as shown in Fig. 36-18*b*. As shown by the block diagram, the signal must pass through all four of these circuits. Hence, the response of the entire circuit is the sum of the individual response curves, as shown by the heavy line in the figure. By proper choice of the Q and resonant frequencies of the individual tuned circuits, essentially flat-topped curves of considerable bandwidth can be obtained. This technique is widely used for obtaining the wide bandpass required in television receivers.

Obtaining a good flat-topped curve of the proper bandwidth usually requires visual alignment using an oscilloscope and sweep generator. In these experiments, the principle of stagger tuning will be demonstrated by detuning the i-f adjustments a certain amount. This will give a rough approximation to a flat-topped curve.

Procedure.

Step 1. Determine which trimmer tunes

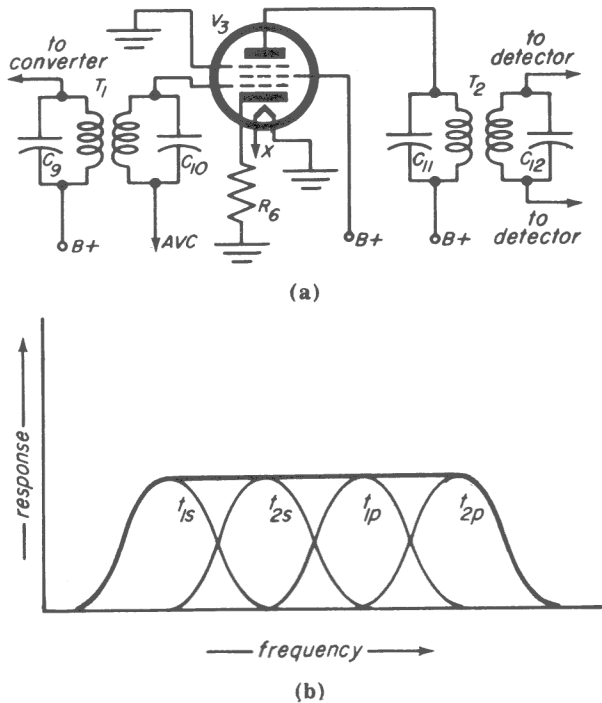


Fig. 36-18

the primary and secondary of each i-f transformer. This can be done by either tracing the leads into the can with a flashlight or by using an ohmmeter, as follows:

Set up the meter to the R x 1 ohms scale, and connect one meter test prod to the red lead of an i-f transformer. Insert the other test prod through the adjustment hole, as shown in Fig. 36-19a. Hold the test prod at the angle shown in Fig. 36-19b so that it clears the mica insulation and touches the top metal plate. When the meter indicates a short circuit, you have located the *primary* trimmer. The other trimmer on this same can is, of course, the secondary trimmer. Label the trimmers, and repeat the process for the other i-f transformer.

Step 2. Carefully align the i-f amplifiers to resonance, in accordance with the procedures given in other lessons.

Step 3. Record the position of the i-f adjustments by making a mark on the screw slot and on the i-f can, as shown in Fig. 36-20.

Step 4. Short pin 5 of the 6SA7 tube to ground with your clip lead to disable the oscillator.

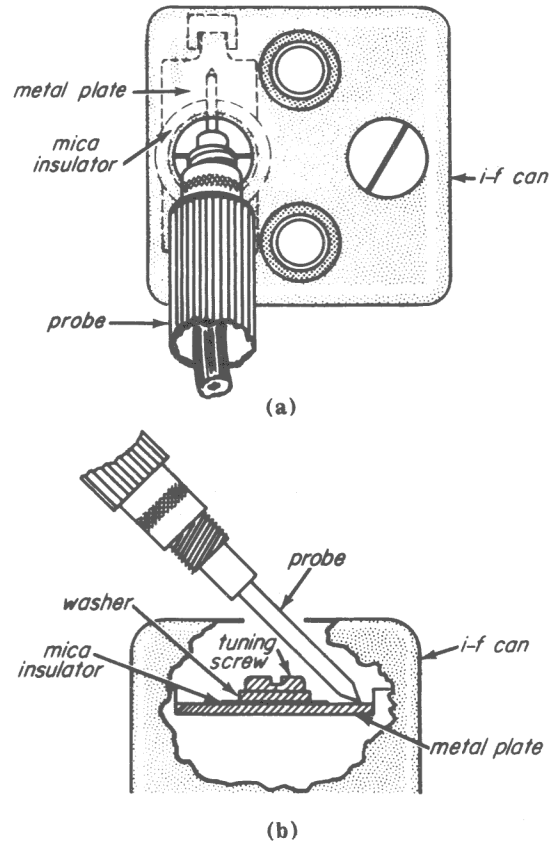


Fig. 36-19

Step 5. Set the signal generator to 455 kc, and connect the signal generator cable to the grid (pin 8) of the converter tube. Turn the AF OUT/INT MOD control on, and adjust the RF ATTN control to midposition.

Step 6. Set up the meter to the 15 VAC range, and insert the positive test lead in the output jack. Connect the meter to the plate (pin) of the 6K6-GT tube and ground.

Step 7. Turn on the receiver, and set the volume control near its minimum position.

Step 8. Rotate the signal-generator tuning dial to about 300 kc, and then slowly rotate the dial up to and past 455 kc, while observing the meter.

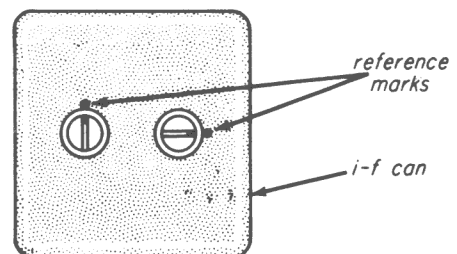


Fig. 36-20

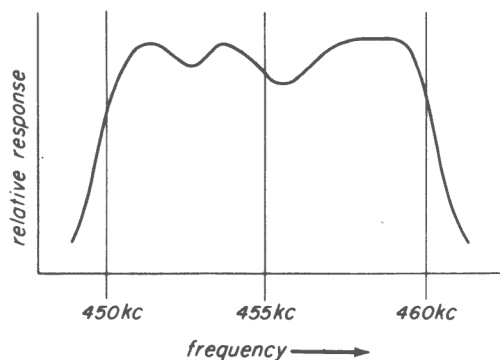


Fig. 36-21

From your observation of the meter, what does the response curve look like? If you wish, you can take data to plot a response curve. It should be a single peaked curve, rising up sharply below 455 kc, and falling off rapidly above 455 kc.

Step 9. Using the location mark on the i-f cans as a starting point, mark off each adjustment hole on the i-f cans into 4 parts as a guide for turning the adjustment screws a specified amount.

Step 10. Carefully turn both *primary* screws 1/8-turn counterclockwise (in the direction of decreasing capacity).

Step 11. Carefully turn both *secondary* screws 1/8-turn clockwise (in the direction of increasing capacity).

Step 12. Rotate the signal generator tuning dial to about 300 kc, and then slowly rotate the dial up to and past 455 kc while observing the meter. From observation of the meter, what does the response curve look like? If you wish, you can take data to plot a response curve.

Step 13. Turn off the receiver and remove the short at pin 5 of the 6SA7 converter tube.

Step 14. Turn on the receiver and tune through the broadcast band. What has happened to the

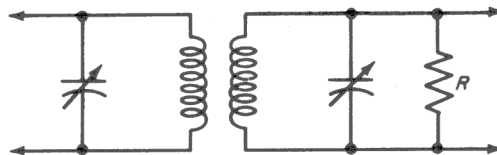


Fig. 36-22

sharpness of tuning and the selectivity of the receiver?

Step 15. Turn off the receiver and restore the i-f adjustments to their original positions.

Discussion. Stagger tuning the intermediate frequency transformers in this way produces a rough approximation to a flat-topped curve that is about 10 kc wide. A typical curve obtained using this procedure is shown in Fig. 36-21. With visual alignment equipment, it is possible to obtain a good flat-topped curve. The increased bandwidth is obtained at the expense of gain, as can be seen by noting that the signal-generator output must be increased to obtain the same amount of deflection after stagger tuning.

Another method for increasing bandwidth is to load each transformer with a resistor, as shown in Fig. 36-22. Only one of the two coupled circuits need be resistive loaded. The size of the resistor depends upon the bandwidth desired. Using smaller resistors increases the bandwidth but reduces the gain. FM receivers using this method usually use resistors of about 100 k-ohms; television receivers, which require much greater bandwidth, use resistors of about 22 k-ohms.

This method of increasing bandwidth is not included in the experimental procedure because the results are similar to that of the other experiments. However, if you wish, you may load down both i-f transformers with a 27 k-ohm resistor and take data for plotting a response curve using the procedure given in previous experiments.

